Chapter: 2. REVIEW OF LITERATURE

Study of review literatures to overcome the aims and objectives of the present study is presented as follows:

2.1. Ichthyofauna study

Fishes exhibit enormous diversity as far as number, size, shape, habitat, behaviour and biology and they occupy almost the half of total number of vertebrates which makes an interesting zone of research. 21,723 living species of fish have been recorded out of 39,900 species of vertebrates (Jayaram, 1999). Of these, 8,411 are freshwater species and 11,650 are marine fish. In 1822, Hamilton’s pioneer work, the Fishes of Ganga, described 269 species of fishes from river Ganga and its tributaries. The comprehensive account of Indian fishes was worked out by Francis Day in (1878, 1889). In the past and present centuries a number of researchers and taxonomists added a valuable contribution on fish diversity, taxonomy, conservation, fishing implements, habitat characteristics with relation to water quality etc.

Studies of freshwater fishes in the Indian subcontinent have been limited to scattered works on commercial fisheries and even these have been largely restricted to some of the major river systems like the Ganges, Brahmaputra and the Yamuna. Day, (1875) described 1,418 species of fish under 342 genera, and a century, later Jayaram, (1981) listed 742 freshwater species under 233 genera, 64 families and 16 orders from the Indian region. Talwar and Jhingran, (1991) estimated 930 species of fresh water fish belonging to 326 genera and 99 families. Menon (1962) has listed 218 species of fishes in whole Himalayas. The checklist of Menon, (1999) lists 446 primary freshwater species under 33 families and 11 orders from the Indian region alone. In India, the workers who made important contribution in the assessment of fish biodiversity in
various water bodies like fish fauna of Chalakudy River, (Raghavan et al., 2008), freshwater fish biodiversity and conservation (Lakra et al., 2010; Sarkar et al., 2007; Sarkar et al., 2008; Sarkar et al., 2011), freshwater fish diversity in Central Western Ghats (Bhatt, 2003), fish biodiversity and conservation priority in Alaknanda river (Singh and Sharma, 1998), fish diversity and conservation status of India (Kar et al., 2006; Ajithkumar et al., 1999; Kumar and Rao, 2009), conservation categories of Siluroid fishes in Northeast Sundarbans, India (Patra et al., 2005).

The extensive study for ichthyofauna study from Indo-Bhutan adjacent areas of Assam region is not yet done properly. Only a few studies have been done by Das and Dutta (2013), reported 70 fish species belonging to 53 genera, 18 families and 7 orders from the Pagladia river. Pathak et al., (2013) reported three species of the genus Olyra (Teleostei: Bagridae) from Indo-Bhutan hill streams of Assam. Baro and Sarma (2014) described overall fish diversity from Sonkosh river. Baro et al. (2014) described ornamental fish diversity from Sonkosh river. Baro et al. (2014) reported the cold water fish diversity and abundances from upper reaches of the river. Baro and Sarma (2015) reported the distribution, habitat and conservation status of threatened fish species of the Sonkosh river.

drainage located in Arunachal Pradesh, Meghalaya, and northern Bengal; together with parts of Assam and the Himalayan foothills between Nepal and Bihar exhibit the most diverse fish fauna. Species richness is highest in the Tista, Kameng, Dikrong, Subansiri and Siang basins. The richness in these areas is due to the diversity of habitats and environments existing between the plains of the Brahmaputra at a low altitude (120–200 m) to the upland cold water regions (1,500–3,500 m) in the hill ranges in Arunachal Pradesh and also in Meghalaya and Assam within a short aerial distance of 200–500 km. Nath and Dey (2000) have recorded a total of 131 species from drainage of Arunachal Pradesh. Ichthyological survey and review of the checklist of fish fauna of Arunachal Pradesh have been conducted by Bagra et al. (2009) and developed a checklist with 213 fish species for the state. They have added 43 species to the previous record of 170 species. This study confirmed the occurrence of five new species described by previous investigations and encompasses the discovery of two new species, although the taxonomic status of 27 species is uncertain and requires additional study. A total of 44 species of fishes belongs to 9 families were identified in the river Siyom of West Siang district, Arunachal Pradesh. Fishes of family Cyprinidae were found to be dominant followed by Balitoridae (Bagra and Das, 2010). Boruah (1999) reported 167 species from the upper Brahmaputra basin, of which 64 species belonged to Cyprinidae, 19 species to Sisoridae and 12 to Cobitidae. Boruah and Biswas (2002) opined that of which about 30 percent may be considered as ornamental varieties. Northeast India is represented by 267 species belonging to 114 genera under 38 families and 10 orders (Sen, 2000). This is about 33.13% of total Indian freshwater fishes. Choudhury (2005) reported that rich ichthyo-diversity of northeast India comprises 297 fish species belonging to 114 genera under 38 families and 10 orders. It forms about
33% of the total Indian fresh water fishes. Kar (2005) reported the occurrence of 103 species of fishes through an extensive survey conducted in six principal rivers in Barak valley (Assam), Mizoram and Tripura. A total of 97 species including exotic species belonging to 56 genera of 26 families were recorded from lower reaches of Brahmaputra river (Sarma et al., 2009). In 2012, Das and Bordoloi, reported a total 82 fish species belonging to 10 orders, 54 genera of 23 families and a total of 62 ornamental fish species were identified belonging to 42 genera, 22 families and 9 orders from the Majuli Island of river Brahmaputra. Tamang (1993) reported about 48 species of fish from Sikkim. However, only 37 species were recorded in 2001 (MOEF, 2002). Recently, Goswami et al., (2012) published lists of 422 fish species from north east India, belonging to 133 genera and 38 families and Vishwanath, (2014) described 266 species of fishes from Northeast India under 81 genera and 13 families.

Recently new species have been discovered from the different parts of the Eastern Himalayan streams. Vishwanath and Nebeshwar (2004) decribed *Schistura reticulata*, as a new species of balitorid loach from Manipur, India. *Schistura fasciata*, a new nemacheiline species (Cypriniformes: Balitoridae) from Manipur, India (Lokeshwor and Vishwanath, 2011). *Parachiloglanis bhutanensis* by Thoni and Gurung (2014) form Bhutan. Recently *Oreichthys crenuchoides, Channa andrao and Badis kanabos, Badis blosyurus* were described from the streams of Assam-Bengal Himalayan foot hills areas. WWF (2015) reported news species discoveries in recent time from the hidden Himalaya.

Some of the pioneering works on ichthyofauna of river Brahmaputra were conducted by Hamilton (1814), MClelland (1839), Beavan (1877), Hunter (1879) and Day (1877 and 1889). Later, during the 20th century, several workers studied the
taxonomy and distribution of fishes in the Brahmaputra river system. Among them Dey (1910) studied the fishery potentialities of Eastern Bengal and Assam. Hora (1937) reported the fish species of the hilly areas of Assam. Motwani et al. (1962) studied the fisheries of river Brahmaputra. Studies pertaining to the certain Fish and Fisheries of the Brahmaputra drainage system and its certain tributaries have been carried out by different Workers (Sen, 1985; Jhingran, 1991; Sinha, 1994; Yadava and Chandra, 1994; Bhattacharya et al., 2000; Lalmohan, 2000; Sarma and Dutta, 2000; Sarma et al., 2005; Sarma and Dutta, 2009, Baro et al. 2014 and 2015 etc.).


Dey (1996) gave a compilation of Indian, indigenous ornamental ichthyofauna, including the freshwater, brackish water and marine ones in his book, “Ornamental fishes”. One of the classic works to describe species wise distribution of Indian indigenous aquarium fishes was undertaken by Chhapgar (1982). A total of 32
ornamental fish species have been reported from Jorhat, Sibsagar, Dibrugarh and Tinsukia district of upper Assam (Pandey et al., 1998). Records of 87 fish species as potential ornamental value have been reported in the state of Assam (Bhattacharjya et al., 2000). Out of 168 fish species, 63 have been considered as food fish and remaining 53 as ornamental fish (Sarkar and Ponniah, 2000). Out of 217 fish species from Assam, 150 species have been listed under potential ornamental value (Bhattacharjya, et al., 2003). Out of 250 fish species recorded from Northeast India, highest number of ornamental fishes (187 species) has been recorded from the Assam (Mahapatra et al., 2004). 61 fish species have been listed as ornamental value from central Brahmaputra valley zone (Sarma et al., 2004). 62 ornamental fishes were reported from flood plain wetlands of upper Brahmaputra basin (Das and Biswas, 2009). 62 fish species from the river island Majuli, Assam (Das and Bordoloi, 2012); 24 fishes from the Silsakho wetland in Kamrup district of Assam (Barua and Sharma, 2013). Gurumayum and Goswami (2002) reported that ornamental fish trade in Northeastern region was unorganised and based on natural collection. The study claimed that 85% of total Indian ornamental fresh water fish trade was from Manipur. Jayalal and Ramachandran (2013) explained that 90% of the freshwater ornamental fish exported from India are wild caught indigenous species.

The Glacier-fed rivers from high altitudes of Himalayan Mountains remain were surveyed by many workers from Bhutan and Nepal. There are many reports of working on cold water fishery resources from rivers and streams of Bhutan. Amongst them Dubey (1978) described the rivers and lakes of Bhutan in detail with data on temperatures and water quality and other factors which affect the fisheries potential. Gurung et al. (2013) examined 66 fish species and gave check list of 91 fresh water fish
species known to occur in Bhutan. Earlier Petr (1999) reported 41 indigenous fish species from rivers and lakes of Bhutan. But study of cold water fish resources and its fishery potential has not been done properly from all the rivers and streams of Indo-Bhutan foot Hill areas of Assam. Some brief works have been done by Acharjee et al. (2005), Pathok et al. (2013), Goswami et al. (2012), Baro and Sharma (2014), Baro et al. (2014), yet the proper scientific information about the diversity, abundances and distribution of cold water fishery resources is meagre. Shrestha (2001) has reported for Nepal a total of 182 fish species belonging to 92 genera under 31 families and 11 orders, as compared to 186 species of 75 genera, 31 families and 11 orders reported earlier. Shrestha (2002) reported a total of 81 cold water species under 37 genera belonging to 2 orders, 7 families and 10 subfamilies is listed, with their updated nomenclature and systematic position according to the recent classification of Jayaram (1999). Genera Naziritor Mirza and Javed, Salnostoma Swainson, Securicula Gunther, Acanthocobatis van Hasselt and Lepidocephalus Bleeker are revised here. A number of species have been either synonymised or merged with others. Shrestha (1990) has reported 31 species including Rita rita (Hamilton-Buchanan) as the threatened species of Himalayan waters of Nepal. Thapa Chetry (2006) identified 92 fish species belonging to 54 genera and 25 families in the wetland of Koshi-Tappu wild life reserve and its surroundings in Nepal. Shrestha (1999) studied the river Bagmati and Gandaki and listed 22 species of fish. She has also proposed river zonation based on the presence of the dominant fish species for the two rivers of Nepal.

The extensive survey was also done by many workers on fish diversity in North Bengal, a foot hill region of sub Himalayan region. The fish fauna represents mostly the Chinese, Malayan and Indian elements of fishes of the Oriental realm (Hora and Gupta,
Shaw and Shebbeare (1937) published in the Journal of Royal Asiatic Society of Bengal an illustrated account of the “Fishes of Northern Bengal” and listed 131 species, a few of which are stated to be exotic. Hora and Gupta (1940) surveyed the Kalimpong Duars and the Terai areas in the Siliguri subdivision of the Darjeeling district and the collections of fish were made from large number of small streams, ponds and ditches. Environment Impact Assessment (EIA) on Teesta Low Dam Project reported 26 fish species in Teesta river among which 9 are commercially important and 5 are migratory in nature (Anon, 2002). Jha et al. (2004) studied the fish fauna of Mahananda reservoir near Siliguri town and identified 49 species of fish. Barat et al. (2005) reported 21 species of fishes from upland Darjeeling. Mukherjee et al. (2011) reported 22 species of endangered, vulnerable and threatened fishes from Darjeeling and 8 species from Siliguri. Acharjee and Barat (2013) reported sustenance of about 65 rheophilic, cold water fish species from 39 genera and 10 families with ornamental, food and sport value of which 11 species were ubiquitously found Teesta river stretch. Sarkar and Pal (2008) studied the diversity of fish in different reservoir and rivers of Himlayan Terai region and altogether 83 species of fish belonging to 24 families and 51 genera were collected. Patra et al., (2011) reported Ichthyofauna diversity from Karala River in Jalpaiguri, a total of 55 species belonging to 8 orders and 20 families were identified.

The freshwater fish biodiversity in the rivers from different parts of the world was also well documented in literature of (Muchlisin and Azizah, 2009). Jayaram, (1999) listed 852 freshwater species of fishes under 272 genera, 71 families and 16 orders, including both primary and secondary freshwater fishes from India, Bangladesh, Myanmar, Nepal, Pakistan and Sri Lanka. The scenarios of freshwater fish extinctions from climate change and water (Xenopoulos et al., 2005), information on freshwater
fish biodiversity in the Yangtze River basin in China (Fu et al., 2003), distribution and conservation status of the endemic freshwater fish of Asia (De Silva et al., 2007), River rehabilitation for conservation of fish biodiversity in Asia (Dudgeon, 2005), European species and habitat monitoring (Schmeller, 2008), fish diversity and its relationships with environmental variables in African basin (Kouamelan et al., 2003), Bergerot et al., (2008) studied the prioritization of fish assemblages for conservation in France. In 1978, Dubey had studied the physiography and cold water fisheries potential of Bhutan, Corbacho and Sanchez (2001) studied the pattern of species richness and introduced species in native freshwater fish faunas of the Guadiana River. King (2002) has reported ecology of fish in Floodplain River of the Southern Murray-Darling Basin. Fu et al. (2003) have studied patterns, threat, conservation and fish diversity in Yangtze River basin of China. Fish diversity and habitat relationship with environmental variables at Meghna river estuary of Bangladesh was reported by Hossain et al, 2012.

2.2. Ichthyofaunal Diversity Indices:

The ability to quantify diversity measuring different diversity indices is an important tool for biologists trying to understand community structure and it help in formulating different conservation measures of an eco-zone. A biodiversity index seeks to characterize the diversity of a sample or community by a single number (Magurran, 1988). The concept of the ‘‘species diversity’’ involves two components: the number of species or richness and the distribution of individuals among species. However, the formal treatment of the concept and its measurement is complex (Williamson, 1973). In flowing waters the numbers of fish species were more numerous with increasing water depth (Sheldon 1968, Bain 1995). Baro et al. (2015) reported diversity of cold water fishes from Sonkosh river and Shannon-Weiner index was ranged from 3.43 -3.54;
dominance index from 0.037 – 0.043 and evenness index from 0.55 -0.66. Vijaylaxmi et al. (2010) have reported the Shannon-Weiner fish diversity index of river Mullameri River within the range of 2.5 - 2.9. Simpson’s dominance index was also reported high (0.09 - 0.1). Patra et al., (2011) found Shannon-Wiener diversity index of ichthyofauna ranged from 3.18-3.75 in Karala river, a tributary of Teesta river near Jalpaiguri town. Murugan and Prabaharan (2012) reported Shannon-Weiner index for fish diversity in Kamala reservoir ranged from 2.2 to 4.10. The Shannon–Weiner diversity index of different sampling indicated a strong relationship with overall species richness, showed considerable variation and ranged from 1.89 to 3.51 and maximum fish diversity index was observed in upper stretch as compared to lower stretch in river Betwa, a tributary of Ganga River system (Lakra et al., 2010).

Evenness measures attempt to quantify this unequal representation against a hypothetical community in which all species are equally common. Pielou (1966) proposed that “evenness” be measured by the ratio between the diversity $H'$ calculated and that which would be obtained, for the number of species surveyed, in case of equal frequencies. Evenness indices standardize abundance and range from near 0 when most individuals belong to a few species, to close to 1, when species are nearly equally abundant (Smith and Wilson, 1996). Patra et al., (2011) reported evenness index for ichthyofauna ranged from 0.887 – 0.949 in the Karala river. Fish communities in riverine systems typically follow a pattern of increasing species diversity and abundance from upstream to downstream (Bayley and Li, 1994).

2.3. Riverine Habitat and Ecology

Running water habitat is a kind of freshwater habitat. The running freshwater environments are called lotic ecosystems for obvious reason of unidirectional water
movements along a slope in response to gravity (Wetzel, 2001). A lotic ecosystem is the ecosystem of a river, stream or spring. The main characteristics of river and stream ecosystem have been summarized by Wetzel (2001), as (i) unidirectional flow; (ii) linear form that occupies little of the total drainage basin area; (iii) unstable and constantly changing channel substrata and morphology; (iv) having most of the biotic metabolism supported by organic matter originally from external allochthonous sources that is imported to the stream or river; (v) high spatial heterogeneity that changes rapidly and frequently; (vi) high variability and individuality of physical, chemical and biological characteristics. Studies on the ecology, environment and fisheries of five major river systems, in addition to reservoirs and flood plain lake fisheries, have been conducted with greater focus on water quality and less on physical habitat parameters (Ghosh and Ponniah, 2001). Habitat structure, water quality, flow regime, and biotic interactions are the major environmental factors that determine water resource integrity (Karr, 1991). Habitat structure has been identified as a major determinant in distribution and abundance of fishes from earlier time (Shelford, 1911). Later the zonation concept was developed by Huet, (1954) where he explained the fish community in longitudinal succession with environmental characteristics. Gordon et al. (2004) wrote a beautiful book named ‘Stream Hydrology’, An Introduction for Ecologists. Allan and Castillo (2007) explained in their book ‘Stream Ecology’ the structure and function of running water. Dudgeon (2008) discussed characteristics of tropical stream and compared with the temperate counterparts in his edited book ‘Tropical Stream Ecology’.

River systems can be described in five dimensions (Lenders and Knippenberg, 2005). The three physical dimensions (longitudinal, transversal and vertical) are key features of river systems (Ward et al., 2002; Van der Velde et al., 2004). The temporal
or fourth dimension (Poudevigne et al., 2002; Lenders and Knippenberg, 2005) represents short and long term changes and is usually elaborated in terms of physical river system processes, such as hydro- and morpho-dynamics, and accompanying phenomena such as succession and rejuvenation. Finally, the social or fifth dimension includes socio-economic activities as well as issues like cultural identity and various positions of humans may hold towards nature (Lenders and Knippenberg, 2005).

Studies on habitat characterization, water quality with relation to fish species of the river ecosystems in India have been done by various workers like Das and Sinha (1993); Rana (1996); Sharma and Agarwal (1999); Mahanta and Patra (2000); Trivedi et al. (2000); Sarkar and Bain (2007); Agrawal et al., 2007; Mishra et al., 2008); Bhandari and Nayal, (2008); Pradhan et al. (2009); Umamaheswari and Saravanan, 2009; Mahananda et al., (2010); Johnson and Arunachalam (2010); Patra et al. (2010); Lakra et al. (2010). Fresh water ecology and principles of river ecology have made significant progress due to efforts made during the past years in India and made significant advancement in the countries. Badola and Singh (1981) and Dobriyal et al. (1983) on the river Ganga. Sangu and Sarma (1985) made studies on river Yamuna. Chako and Ganapati (1952) also studied the hydrology of Surli river of Madurai district.

Literature revealed lots of significant works on the ecology and fishery of North east Indian rivers by Biswas and Boruah (2000) reviewed the fisheries and ecology of the Northeast India with special reference to the Brahmaputra river system. Acharjee et al. (2005) studied biotic spectrum of a hill stream (Manas river) of Assam. Daimari et al. (2005) worked on ecology and fishery of river Subanshiri (Arunachal Pradesh). Hazarika (2010) documented the fluvial environment of Jiadhal river basin of Dhemaji district, Assam. More recently (Dutta, 2012) reported hydrology and fishery potential of

In other counties several workers studied the riverine habitat (viz. Merz and Sekta, 2004; Diana et al., 2006; Minns, 2001; Agraie and Obi, 2009; Sutin et al., 2007; Alam et al., 2007; Iqbal et al., 2004; Adefemi and Awokunmi, 2010 and fish habitat assemblages by (Naiman and Latterell, 2005; Korai et al. 2008; Tongnunui and Beamish, 2009; Tuya et al., 2009; Hermoso et al., 2009; Kirsten (2011).

A considerable quantity of research has been carried out on the physico-chemical parameters of riverine water and their impact on aquatic biota in India (Pande et al., 1988; Chakraborty, 1998; Dhanapakiam et al., 1999; Shastri, 2000; Barat and Jha, 2002; Bhattacharya (2005), Sarkar et al., 2010, Mandal et al., 2012 and Bhattacharya et al. (2017).

The air temperature is the resultant effect of several meteorological factors such as solar radiation, humidity, wind etc. and also the latitudinal and altitudinal position of the place under study (Wetzel, 2001). The sun light radiation and the air temperature
influence the water temperature of an aquatic system to a great extent. The main significance of temperature for flowing waters is through its effect on metabolism and the capacity of water to hold dissolved oxygen (Lewis, 2008). McGregor and Neuwolt (1998) calculated that the rate of decrease in temperature with elevation within the tropics is approximately 0.65°C per 100 m of elevation. The natural waters in tropical areas generally show a higher production due to more heating in the ecosystem as Probst (1950) found an average increase in carp yield of 22 kg per hectare just for 1°C rise of temperature. Water temperature plays a very important role in some physiological processes like release of stimuli for breeding mechanisms in fish, both under natural and artificial conditions (Hora, 1945; Chaudhuri, 1964). Sehgal (1974), Joshi et al., (1978), and Sehgal (1988) have summarized average water temperature in three Himalayan zones i.e. Greater Himalayan zone (4000-2000 m. asl) is 13.4°C; Lesser Himalayan zone (2000-1000 m. asl) is 18.7°C; Siwalik zone (below 1000 m asl) is 22.9°C. Available literature indicated that in the north eastern Himalayan Rivers, water temperature ranged from 5.6°C to 30°C. In rivers of Bhutan Himalaya water temperature ranged from 8.5°C to 26°C (Dubey, 1978). Lowest temperature observed in the river Kalingkhola (October) but highest temperature found in the river Torsa and Sonkosh (April-June). Thapa et al., (2010) reported highest temperature 29.6°C in glacier-fed Trishuli River in Nepal. Bhadra et al., (2003) and Barat and Jha (2002) reported in the foot hill river (Torsa and Mahananda of North Bengal) water temperature varied from 17.5°C- 34°C. The water temperature falling within the tolerance limits of the snow trouts and may be termed as cold (Jhingran and Sehgal, 1978). Badola (1979), Sharma and Mishra (2002) reported that glacier fed river water
were cooler than the spring fed rivers. In the Himalayan rivers water temperature increased towards downstream (Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010).

Water velocity is the key factor in riverine systems influencing their ecology. Flushing rates of river ecosystems are comparatively rapid and directional. Water velocities are driven by the gravitational weight of the water moving down the slope and are controlled by the channel morphology and elevational gradient, water volume, type of substratum, and obstructions (Wetzel, 2001). The speed of the water flow is typically based on variability of friction with the bottom or sides of the channel, sinuosity, obstructions, and the incline gradient (Allan, 1995). Lampert and Sommer (2007) opined that stream velocity depends on the incline and smoothness of the substrate, but also on the cross sectional area of the stream. In addition, the amount of water input into the system from direct precipitation, snow melt and/or groundwater can affect flow rate. Flowing waters can alter the shape of the stream bed through erosion and deposition, creating a variety of habitats, including riffles, glides, and pools (Cushing and Allan, 2001). Water velocity of Himalayan River ranged from 0.06 m sec\(^{-1}\) to 3.9 m sec\(^{-1}\). Highest velocity was found in the glacier-fed river Alaknanda (Nautiyal, 2010). Shrestha (1990) reported water velocity in Karnali River in Nepal ranged from 0.3 to 4.5 m sec\(^{-1}\). Dash (1947) wrote the water current of Teesta river in Darjeeling is very swift, running in places at the rate of 14 miles/hour i.e., 6.26 m sec\(^{-1}\). In the river Brahmaputra water velocity varied from 0.06 to 0.62 m sec\(^{-1}\) (Biswas and Boruah, 2002). Sharma \textit{et al.}, (2007) observed that water current remained high throughout the year but it attained the peak value during monsoon months (July-August) due to frequent flash floods. Water velocity decreased downstream (Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010) and maximum velocity observed in monsoon
months and minimum in winter months. Water velocity of glacier-fed river was found higher than spring-fed river (Sharma and Mishra, 2002).

Electrical conductivity is simply the relative amount of electricity that can be conducted by water, frequently employed for monitoring surface and ground water and desalination plants. Pure water is a poor conductor of electricity. The conductivity of water depends upon the concentration of ions and its nutrient status and the variation in dissolved solid content is indicated by conductivity measurements. Conductivity is the inverse of resistivity, (or 1/ohm cm⁻¹) is linked to the level of mineral electrolytes salts dissolved in water (Faurie et al., 2001). The specific conductance of the common bicarbonate type river water is closely proportional to concentration of the major ions like Ca²⁺, Mg²⁺, Na⁺, K⁺, CO₃²⁻, SO₄²⁻, Cl⁻ (Rodhe, 1949). Boruah and Biswas (2000) reported range of conductivity as 87-145.7 μmhos cm⁻¹ in the Brahmaputra River. Specific conductivity of north western Himalayan rivers ranged from 20 to 468.2 μmhos cm⁻¹ and it increased upstream to downstream (Singh, 1988; Mathur, 1991; Nautiyal, 2001). In glacier-fed Trishuli river system of Nepal it varied from 8.2 to 534.0 μmho cm⁻¹ (Thapa et al., 2010) and in the rivers of Bhutan it was ranged from 20-140 μmho cm⁻¹ (Dubey, 1978). Bhadra et al. (2003) reported specific conductance of a foot hill river Torsa in north Bengal, varied from 100-280 μmho cm⁻¹.

pH is a measurement of the acidity or basic quality of water. At extremely high or low pH levels (for example 9.6 or 4.5), the water becomes unsuitable for most organisms. By definition, pH of a solution is the logarithm of the inverse of the concentration of hydronium ions (H₃O⁺), produced as a result of dissociation of water (Faurie et al., 2001) pH = -log [H₃O⁺]. The pH of natural water is governed to large extent by the interaction of H⁺ ions arising from the distribution and dissociation of
H$_2$CO$_3$ and from OH$^-$ ions produced during the hydrolysis of bicarbonate. The pH of natural water ranges between the extremes of <2 -12 (Wetzel, 2001). In the fresh water, the variations in pH are intimately linked to the nature of soils of basin and to the rainfall. Gathers of literature indicated that the pH range generally varies from 6.5 to 8.7 in north western Himalayan Rivers. However Pathani and Upadhyay (2003) found pH 10.05 in the river Ramganga (west) during winter. Dubey (1978) reported pH ranged from 6.8 to 8.7 in the rivers of Bhutan, but NWWFCC (2001) recorded highest 9.4 pH value. Das and Dutta, (2012) reported pH of Pagladia river, Assam water ranged from 6.64 to 7.20 at different stations with little seasonal variations. pH value along with the study of the physico-chemical parameters of beels, wetlands and tributaries of Brahmaputra and Barak river system of Assam were given in the recent works of Boruah (1999), Acharjee et al. (2005), Nath and Dey (2008). In the rivers of Nepal Himalaya values of pH varied from 5.4 to 8.6, lowest value observed by Juttner et al. (2003) and highest value by Thapa et al. (2010) and Juttner et al. (2003). Shrestha (1990) reported that pH value around 8.0 in Karnali river of Nepal. Rivers of north eastern Himalaya showed pH values ranged from 6.0 to 8.2, lowest value found in the Siyom river of Arunachal Pradesh (Bagra and Das, 2010) and highest value in the river Brahmaputra (Biswas and Boruah, 2002) with an average value of 7.6. Haque et al. (2010) found alkaline pH in the river Teesta in Sikkim. Chakraborty et al. (1959) recorded pH more or less constant at 8.0 throughout the year with a slight variation of ± 0.2 in Jamuna river. Kumar and Bhagat (1978) observed pH range of 7.1 to 7.8 in streams of Kashmir. The largest fish groups are usually produced in water like just on the alkaline side of neutrality between pH 7.0 and 8.0 (Roule, 1930). The limit above or below which pH has a harmful effect is given by Ohle (1938) as 4.8 and 10.8. Several
workers like Hannan and Yong (1974); Bais et al., (1995) have reported low pH during the low photosynthesis due to formation of carbonic acid.

Dissolved Oxygen (DO) in water is a most important chemical constituent of lotic ecosystems. It enters the water mostly via diffusion by the water-air interference. Oxygen solubility in water decreases as water temperature increases. Fast, turbulent streams expose more of the water surface area to the air and tend to have low temperatures and thus more oxygen than slow, backwaters (Giller and Malmqvist, 1998). The range of DO (0.4-15.2 mg L⁻¹) in Himalayan Rivers reported as lowest value in river Tawi in Central Himalaya (Sharma and Choudhury, 2011) and the highest value from river Gaula (856 m asl) of Kumaun Himalaya (Singh, 1990). Badola (1979) observed highest value of 18.1 and 16.8 mg L⁻¹ of dissolved oxygen in glacier-fed river Alaknanda and spring-fed river Nayar respectively and the value of DO decreased downstream (Singh, 1988; Mathur, 1991; Nautiyal 1996, 2001). In the rivers of Nepal Himalaya values of dissolved oxygen ranged from 5.6 to 14 mg L⁻¹, lowest value observed by Thapa et al., (2010) in Trishuli River where as highest value reported by Ranjit (2002) in Sunkoshi River. Values of dissolved oxygen ranged from 7.0 to 13.5 mg L⁻¹ in the rivers of Bhutan Himalaya (Dubey, 1978; NWWFCC, 2001). In the rivers of north eastern Himalaya values of DO ranged from 3.6 to 15.4 mg L⁻¹. Both values found in the river Brahmaputra (Jhingran, 1991; Biswas and Boruah, 2000) with an average value of 9.4 mg L⁻¹. Haque et al. (2010) found its range to be 6.8 to 9.89 mg L⁻¹ in the river Teesta in Sikkim. Hancock (1973) discussed about seasonal average and fluctuations in DO; he reported that it was maximum in winter and minimum in summer. The decreased water temperature during winter season has a greater capacity to hold DO than warm water and probably led to a lower rate of respiration thereby
allowing maximum DO in winter (Welch, 1952). Dudgeon (2008) observed that oxygen concentration is almost constant with increasing altitude because the decreasing atmospheric pressure of oxygen with altitude offsets the effect of decreasing temperature (and thus increase solubility) but, some authors indicated the value of DO decreased downstream (Singh, 1988; Mathur; 1991; Nautiyal, 2001).

Free Carbon dioxide (FCO₂) dissolves in water in varied amounts depending on partial pressure and temperature of the environment. Apart from this, decomposition of organic matter and the respiration of aquatic organisms contribute to the free CO₂ present. Water percolating through the vegetation and soil take up CO₂ released from the soil air. CO₂ combines chemically with water to form carbonic acid (H₂CO₃), dissociates partly to produce hydrogen (H⁺) and bicarbonate (HCO⁻₃) ions (Faurie et al., 2001). Free CO₂ shows wide fluctuations because of its capacity to combine with Calcium, Magnesium and other elements, its utilization during photosynthesis process and release during respiration of organisms. Different literature indicated that in general the values of free CO₂ ranged from 0.0 - 8.0 mg l⁻¹ in the north western Himalayan Rivers, but Badola (1979) reported highest value of 35.6 mgL⁻¹ and 18.8 mgL⁻¹ in spring-fed river Nayar and glacier-fed river Alaknanda respectively. Values of free CO₂ ranged from 0.96 - 12.3 mg L⁻¹ in the north eastern Himalayan Rivers. Thapa and Pal (2011) reported range of free CO₂ from 4.15 to 5.92 mg L⁻¹ in Nepal Himalaya. Values of free CO₂ varied from 1.0 to 8.9 mg L⁻¹ in the rivers of Bhutan (NWWFCC, 2001). The reports of Biswas and Boruah (2002) ranged from 1.9 to 12.3 mg L⁻¹ in the river Brahmaputra with an average value of 5.2 mg L⁻¹. Lowest value reported in winter and pre-monsoonal months and highest value in post monsoonal months (Gautam, 1990;
Concentration of free CO\textsubscript{2} increases from upstream to downstream (Pathani and Upadhyay, 2003).

Total alkalinity is a measure of bicarbonates, carbonates and hydrates. Alkalinity plays an important role in aquatic production and is associated with free CO\textsubscript{2} and pH. Bicarbonate is abundant in the water with a pH of 4.5 – 8.3 (Jhingran, 1991). In rivers and streams of the north western Himalaya total alkalinity ranged from 10 to 221.6 mg l\textsuperscript{-1}. Lowest value observed in the river Ramganga (W) and Bhagirathi (Pathani and Upadhyay, 2003; Nautiyal, 2010) and the highest value found in the hill-stream Chandrabhaga of Garhwal Himalaya (Sharma \textit{et al.}, 2007). In the rivers of Nepal Himalaya concentration of total alkalinity ranged from 10 to 190 mg l\textsuperscript{-1}, both the values observed in the river Trishuli (Thapa \textit{et al.}, 2010). However, Shrestha (1990) found total alkalinity of 92 mg l\textsuperscript{-1} in the river Karnali. NWWFCC (2001) recorded range of total alkalinity from 13 to 120 mg l\textsuperscript{-1} in the rivers of Bhutan. In rivers and streams of the north eastern Himalaya total alkalinity ranged from 12 to 207.7 mg l\textsuperscript{-1}. Lowest value observed in the river Pachin of Arunachal Pradesh (Hussain and Ahmad, 2002) and the highest value was found in the hillstreams of north eastern Himalaya (Bhattacharjya \textit{et al.}, 2002). Biswas and Boruah (2002) reported range of total alkalinity from 44.3 to 110.8 mg l\textsuperscript{-1} with an average value of 63.4 mg l\textsuperscript{-1} in the river Brahmaputra. Total alkalinity varied in the river Teesta in Sikkim from 10-80 mg l\textsuperscript{-1} (Haque \textit{et al.}, 2010). Value of total alkalinity increased downstream (Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010; Pathani and Upadhyay, 2003). Spring-fed rivers have higher value of total alkalinity than glacier-fed rivers (Sharma and Mishra, 2002). According to Bishop (1973) low alkalinity in the monsoon months were due to dilution effect. Similar observations were also reported by Dhanapakiam \textit{et al.} (1999) and Shastri and Pandse
Maximum total alkalinity during winter was also reported by Chakraborty et al. (1959), Singh (1990), Mishra et al. (1998), and Thapa and Pal (2011) which was associated with high winter pH. Increase of total alkalinity downstream in both the streams, similar observation has been made by other investigators in the Himalayan streams (Singh, 1988; Mathur, 1991; Nautiyal, 2001, 2010; Pathani and Upadhyay, 2003). In streams of the Venezuelan Sierra Nevada, alkalinity rose from 7–32 mgl⁻¹ CaCO₃ (3180–3735 m asl) to 9–519 mgl⁻¹ CaCO₃ (830–1650 m asl) (Segnini and Chacón, 2005). A similar downstream increase has been described for the Purari River, Papua New Guinea (Petr, 1983).

Maximum chloride content has been correlated with high degree of organic pollution and eutrophication. Contamination of water from domestic sewage can be monitored by chloride assays of the concerned water bodies. This is because human and animal excretions contain an average of 5 gmL⁻¹ chloride (Paramasivam and Sreenivasan, 1981). In natural freshwaters, chloride concentration remains quite low and is generally less than that of sulphates and bicarbonates. Global average chloride ion composition of unpolluted rivers is 3.05 mgL⁻¹ (Meybeck and Helmer, 1989). In Asia mean composition of chloride ion in river waters is 8.7 mg L⁻¹, whereas world average is 7.8 mg L⁻¹ (Livingstone, 1963). The most important source of chlorides in the waters is the discharge of domestic sewage. Available literature indicated that in general the value of chloride concentration in the western Himalayan Rivers ranged from 0.12 to 20.3 mg L⁻¹, lowest value found in the river of Kosi in Uttaranchal (Bhandari and Nayal, 2008) and the highest value observed in Tehri dam near the confluence of Bhagirathi and Bhilangana (Agarwal and Rajwar, 2010). Gautam (1990) reported concentration of chloride in the river Bhagirathi varied from 2.8 to 4.3 mg L⁻¹.
Chloride concentration of Torsa river ranged from 5.8 to 11.1 mg L\(^{-1}\) as observed by Bhadra et al. (2003). Sharma and Chowdhary (2011) found range of chloride concentration from 21.95 to 59.88 mg L\(^{-1}\) with an average value of 36.81 mg L\(^{-1}\) in the river Tawi of Central Himalaya. Thapa and Pal (2011) reported values of ranged from 7.11 to 11.3 mg L\(^{-1}\) in Nepal Himalaya. Shrestha (1990) observed 6 mg L\(^{-1}\) in the Karnali River. Biswas and Boruah (2000) reported range of chloride concentration from 1.9 to 10.2 mg L\(^{-1}\) with an average value of 5.6 mg L\(^{-1}\) in the river Brahmaputra. Barat and Jha (2002) reported highest value of 39.4 mg L\(^{-1}\) in the river Mahananda located in the foothill of Darjeeling Himalaya. Thapa and Pal (2011) and Mondal (2009) observed highest seasonal value in of chloride in winter and post monsoon months and lowest in monsoon variations.

Total hardness of a water is governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate (temporary hardness) and with sulphates, chlorides, and other anions of mineral acids (permanent hardness). The term hardness is frequently used as an assessment of the quality of water supplies (Wetzel, 2001). Principal cations imparting hardness of natural waters are calcium and magnesium. However, other cations such as strontium, iron, and manganese also contribute to the hardness. The anions responsible for hardness are mainly bicarbonate, carbonate, sulphate, chloride, nitrate and silicates etc. (Trivedy and Goel, 1984). Hardness is called temporary if it is caused by bicarbonate and carbonate salts (cations), since it can be removed simply by boiling the water. Permanent hardness is caused mainly by sulphates and chlorides of metals. According to Swingle (1967), a total hardness of 50 mg L\(^{-1}\) is the dividing line between soft and hard water. Kannan (1991) proposed that water with a hardness value 0 - 60 mg L\(^{-1}\) is considered as soft. In general,
total hardness of north western Himalayan River ranged from 25 to 138 mg L\(^{-1}\), lowest value found in the river Ramganga (west) of Uttarakhand (Pathani and Upadhyay, 2003) and highest value observed in Ramganga river (Bhatt and Pathak, 1990). Gautam (1990) observed in mountainous Bhagirathi at Uttarkashi, Tehri and Deobrayag, the value of total hardness ranged from 27 to 71 mg L\(^{-1}\), being minimum in high flow seasons and maximum in lean season. However, Kumar and Dua (2009), reported range of total hardness varied from 80 to 730 mg L\(^{-1}\) in river Ravi. During his study of the five lotic water bodies in Darjeeling, Mukhopadhyay (1996) observed a lower range of hardness varying between 5.0 and 17.0 mg L\(^{-1}\). Haque et al., (2010) reported total hardness of Teesta river water in Sikkim ranged from 9.5 to 20 mg L\(^{-1}\). Total hardness of the river Mahanada ranged from 16.2 to 28.4 mg L\(^{-1}\) (Barat and Jha, 2002) in Darjeeling Himalayan foot hill. In Nepal Himalaya total hardness ranged from 27.63 to 96 mgL\(^{-1}\), but Thapa et al. (2010) found total hardness ranged from nil to 320 mgL\(^{-1}\) in the river Trishuli River. Shrestha (1990) observed total hardness 104 mgL\(^{-1}\) in Karnali River. NWWFCC (2001) reported total hardness ranged from 12 to 120 mgL\(^{-1}\) in the rivers of Bhutan. Biswas and Boruah (2002) reported range of total hardness from 53.7 to 106.5 mg L\(^{-1}\) with an average value of 67.1 mg L\(^{-1}\) in the river Brahmaputra. The maximum total hardness in winter season was obtained by Mishra et al., (1999), Thapa and Pal (2011) they related it to low volume of water and slow current of water. Minimum quantity of total hardness in rainy season may be due to more dilution of water (Patralekh, 1994).

2.4. Fishing gears and Crafts

Available literature reports that several forms of fishing gears have been recorded from Northeast region which includes diverse forms of fishing nets, bamboo traps,
harpoons, hooks and lines to catch the fishes. But there appears to be no published documents on the fishing gears and methods of fishing from Sonkosh river system. The relevant information was gathered from other water bodies and adjacent places of Northeastern region. Selection of fishing methods and gear are influenced by various factors such as physiography of the water body, nature of fish stock, characteristics of raw material from which gears are fabricated (Choudhury, 1992). The earliest record of conventional fishing gears and their mode of operation were made by Day (1877). Subsequently, the fishing gears of the inland waters were reported by Job and Pantalu (1958) and Joseph and Narayan (1965). Yadava et al. (1981) and Yadava and Choudhury (1986) accounted the special devices used in the floodplain lakes of Brahmaputa river. Islam et al. (2013) described diversity of fishes and fishing gears and crafts from Kulsi river Assam. Manna et al. (2011) described both fishing gear and craft used along the length of the southern river Krishna. Fishing Craft and Gears used by professional fishermen in Bhopal district for commercial fish culture practices of Bhopal District, Madhya Pradesh was listed by Chourey et al. (2014). All the non-selective nets reported from the Hooghly-Matlah estuarine system are highly destructive in nature (Remesan et al. 2009). Impact of fishing nets studied by Laxmappa and Bakshi (2014) in Krishna river of Telangana reported that the minute mesh size fishing gears, like seine nets used in the catching of all sizes of fish impacting the fisheries in the river. The use of this kind of fishing gears is also the major cause of sharp decline of the economically important Indian major carps in the river. Literature from the abroad also emphasis the similar type of conservation impact on the aquatic ecosystem. Mohammed and Ali (2011) reported the impact of selective and non-selective fishing gears from the White Nile River, Khartoum State, Sudan.
There are many authors who have described fishing gears and their methods of operation from the Himalayan regions include Procter et al. (2012) from Bhutan, Negi and Kanwal (2009) from the Garwal region of Uttarakhand; Tag H et al. (2005), Murugnandam et al. (2014), Srivastava et al. (2002) from the Kumaon of Uttarakhand; Acharjee and Barat (2010) from Darjeeling; Lalthanzara and Lalthanpuii (2009) from Mizoram and Nath and Dey (2000) and Dutta and Bhattacharjya (2008) from Arunachal Pradesh. Shrestha (1981, 1999) have described a substantial number of techniques from Nepal.

From different parts of the India many workers have described about different traditional methods of fishing practices done by fisherfolks but very little information is available from the Indo-Bhutan foot hill districts of Assam. From India Chopra et al. (1958) reported 112 plants with piscicidal action, out of which 40 varieties belonging to North-east region. Around 15 species of plants were reported to be used by Bhil tribe of Ratlam district, Madhya Pradesh Dinesh, (2010). Samajdar and Saikia (2014) from the Birbhum district of West Bengal. Eleven numbers of most commonly used piscicidal plants of Nagaland are reported to be used in ethnobotanical purposes. A total of 21 plants significant for ethnofisheries have been listed from Arunachal Pradesh to be used by Miri tribe (Tag et al., 2005). Barua et al. (2010) reported the traditional fishing gears of the Brahmaputra valley and then Boruah et al. (2013) reported 28 different traditional trapping device and methods from the Brahmaputra valley of Assam. Sharma (2001) described traditional fishing methods and fishing gears of Assam. Purkayastha and Gupta (2014) reported 12 different types of fishing gears that is used by the fisherfolks of Chatla floodplain areas from the Barak valley of Assam. Bhagawati and Kalita (1987) studied the traditional fishing methods in some beels of Kamrup district, Assam.
2.5. Threatened and Rare Fish Species

The threatened as well as the endemic fish species of the eastern Himalaya and its down-stream region were studied by many ichthyologists and organizations. Shrestha (1990a) had given the list of several fish species occurring in the various power project areas as being in danger of extinction, threatened or restricted in distribution. NBFGGR, Lucknow in 1992 had identified nine endemic fishes (Ompok pabda, O. pabo, Labeo dyocheilus, Semiplotus semiplotus, Olyra longicaudata, Psilorhynchus homaloptera, Noemacheilus elongatus, Balitora brucci and Barbus dukai) of Northeast region as most 'threatened'. Sinha (1994) has listed 13 species as threatened from North east. Yadav and Chakadra (1994) reported total disappearance of some species from the landing in Brahmaputra river since 1975 onwards. Labeo dyocheilus and Mystus vittatus have not been reported by them since 1977 from river Brahmaputra. Recent report (Biswas and Barua, 2001) showed dominancy of undersized fishes in fish landings in North Eastern states. Of the 320 species assessed during the workshop CAMP (1997) about 105 were from Northeastern region and among these five species were categorized as critically endangered (CR), one extinct in the wild (EW), 31 were endangered (EN), 46 were vulnerable (VU).

2.6. Ichthyofauna Conservation

Throughout the world, freshwater ecosystems are experiencing serious threats to both biodiversity and ecosystem stability. This situation has been recognized by numerous authors (Williams et al. 1989; Warren and Burr 1994; Cowx 2002), and many strategies have been proposed to solve this crisis by Cowx 2002; Crivelli 2002; Cory and Cooke, 2004). Shrestha (1990a) has given the list of several of the species occurring in the various power project areas as being in danger of extinction, threatened or
restricted in range. The review indicates that dams and their resulting reservoirs can have positive or negative impacts to humankind, depending on its size and how it is constructed. Values of inland capture fisheries and dams construction at the Lower Mekong and Ganga Basins was described by Chong and Ahmed (2002). They also reviewed that dam construction can cause trans-boundary issues, such as that caused by the barrage at Farakka between India and Bangladesh. Detailed studies required for conservation and management of the large Indian rivers are very less except few (Payne and others 2004; Sarkar et al. 2008, 2010). Sarma et al. (2006), Islam and Tanaka (2007) worked on conservation of *Tor* species Himalayan water. Works done by various ichthyologists in the past Hora 1937, 1939, Menon 1974, Shrestha 1990, Talwar and Jhingran, 1991, Goswami et al., 2012) have contributed in the ichthyofaunal conservation measures of Himalayan and Indo-Gangetic plain. For the conservation of rare fishes of the Himalayan region Shrestha (1990b) studied on habitat and ecology of waters. A remarkable works on the evaluation of north-eastern fishes potential as cultivable, sport and ornamental with their conservation and endemic status was done by Sarkar and Ponniah, 2006. The rivers impacted by high human population growth, construction of high ways, roads, bridges, dams, destruction of riparian vegetation and water shed forest cover, denudation causing high siltation, boulder and sand lifting, landslides, disposal of untreated sewages, indiscriminate use of pesticides and fertilizer in agricultural practices, altered land use pattern, rampant fishings were reported from Darjeeling hills regions (Acharjee and Barat, 2010). It is also mentioned that Jhingran and Sehgal (1978), Uniyal et al. (2002) and Srivastava et al. (2002) have worked on illegal fishing methods used in the Himalayan rivers causing decline in fish population.